NANO-TEXTURED FIBER COATINGS FOR ENERGY ABSORBING POLYMER MATRIX COMPOSITE MATERIALS

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1. INTRODUCTION

To meet the weight and performance goals of emerging Army Future Combat Systems, lightweight glass reinforced polymer (GRP) composite materials have been proposed as candidate materials to meet structural and ballistic performance requirements. During manufacture of the glass fibers a thin coating is applied for protection as well as control of performance in composite articles. Conventional glass-fiber coatings (sizings) use organofunctional molecules known as silane coupling agents to enhance the adhesion between the glass fiber reinforcement and the polymeric matrix and to increase the durability of the composite. For industrial glass fiber manufacturing the silane-coupling agent is applied as one of the constituents in a multicomponent fiber sizing package formulation during the initial stages of production. Sizings are essential to the processing and performance of advanced composite materials, yet they are poorly understood. For example, existing sizings are not optimized to simultaneously tailor the static and dynamic response of composite materials. Yet, it has been recognized that these sizings affect structural durability, impact resistance, and damage tolerance of fiber-reinforced composites. Published research indicates that the impact response of a GRP can be tailored for high-energy absorption by designing weak fiber-matrix interfacial interactions. Conversely structural performance (strength) is achieved by strong fiber-matrix interfacial interactions. Hence, the aforementioned trade-offs exist. Although the achievement of simultaneous high strength and energy absorption levels is desirable, the technology has not been available. New approaches are now available to overcome these traditional materials shortcomings.

2. EXPERIMENTAL

The glass-fiber sizing research that has been performed in our laboratories has systematically examined the nature of the glass-fiber thermosetting polymer interface to develop the fundamental understanding that was necessary to propose and validate an entirely new class of sizing materials. Specifically, we have employed mixed organic functionalities of varied reactivity towards the polymeric matrix phase to produce bond strengths that are dependent on the viscoelastic properties of the matrix and fiber coating. That is, we have designed an inherent "viscoelastic switch" at the fiber-matrix interphase that yields strong fiber-matrix interactions at low strain rates and weak fiber-matrix interactions at high strain rates. This triggered response is coupled with optimized post-failure frictional energy absorption mechanisms via fiber pullout. We have applied inorganic-organic sol-gel chemistries to develop silane-based glass fiber sizings that possess increased nano-surface roughness in comparison to standard commercially produced glass fibers. The result has been an increased coefficient of friction between the fiber and matrix during the fiber pullout stages of composite failure, resulting in enhanced energy absorption in the composite. These results were first documented micromechanically on model composite specimens then the materials were scaled-up to demonstrate their behavior in macroscale composite materials.

3. RESULTS

The structural and impact performance of composites produced using our patent pending fiber-sizings was evaluated on realistic composite components. The unique sol-gel based inorganic-organic hybrid fiber sizing formulation has now been successfully applied at a commercial E-glass manufacturing facility to produce rovings as well as woven fabric reinforcements. Figure 1 shows the successful nano-texturing of the fiber surfaces produced on a commercial scale. Composite materials were manufactured using these specialized fabrics and the structural and impact energy responses of E-glass fiber reinforced composites have been measured. Figure 2 captures the impact energy absorption and structural performance of composites produced using state-of-the-art commercial sizings and the ARL custom sizings. These results show the traditional trade-offs found when using commercially available fibers that have been coated with either a structural or ballistic sizing. In comparison, these trade-offs do not exist for the ARL sizing. The impact and structural performance of the composites are both excellent. Furthermore, we have demonstrated that the impact performance of composites fabricated with these low-cost E-glass fibers (ARL sizing) is equivalent to

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the significantly more expensive S-glass systems. A 40% increase in the energy absorption of composites fabricated with no loss in structural composite properties will enable the use of composite materials in applications where they have not been used previously, perhaps with reduced cost.

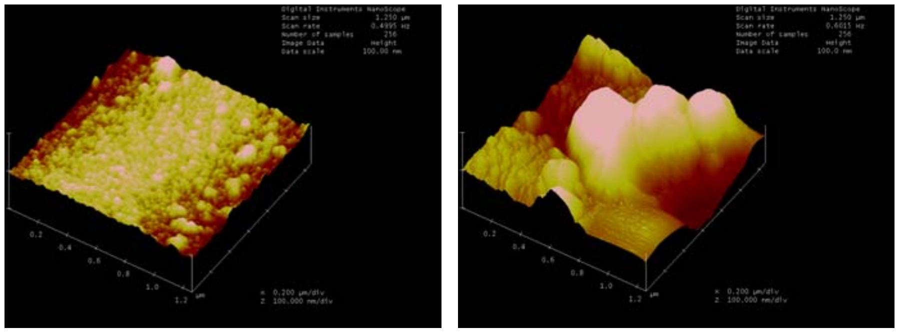

Figure 1. Surface AFM images of standard commercial fiber (left) in comparison to ARL nano-roughened commercially produced fiber.

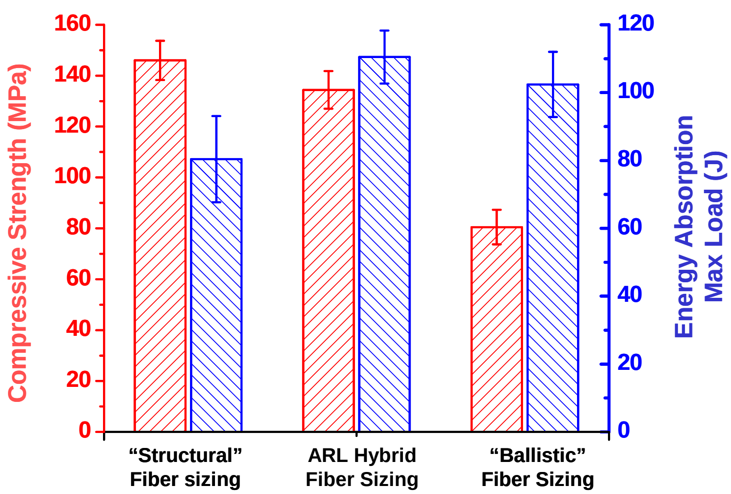

Figure 2. Mechanical performance of composites with various sizings. The ARL sizing shows exceptional performance in both energy absorption and compressive strength